PIPELINE DAMAGE PREVENTION THROUGH THE USE OF LOCATABLE MAGNETIC PLASTIC PIPE WITH A UNIVERSAL LOCATOR

THIRD MILESTONE STATUS REPORT

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Report Issue Date November 15, 2004

DOT Contract OTA DTRS56-02-T-0006

Submitted by

Gas Technology Institute
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GTI Project Number: 61161/30802-63

Submitted to

U.S. Department of Transportation
Research and Special Programs Administration
Office of Contracts and Procurements, DMA-30
400 7th Street, S.W., Room 7104
Washington, D.C. 20590-0001

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OBJECTIVE OF THE R&D PROJECT

The primary objective of this research project is to develop economical magnetic plastic polyethylene (PE) gas distribution pipe materials that can be accurately and reliably located from above ground, using a hand-held magnetic locator, to mitigate damage to the US gas pipelines. The specific goals of this project involve the development of PE gas pipe materials having reduced amounts of magnetic powder, compared to the previously developed POF magnetic PE pipes, but with a sufficiently high magnetic field that can be detected from above ground.

BACKGROUND

GTI completed the proof-of-feasibility (POF) phase that involved the development of magnetic plastic pipes that can be located from above ground. In this POF phase, the PE resin was mixed and compounded with strontium ferrite magnetic powder. This compound was then made into palletized material that was used to extrude magnetic medium-density (MD) and high-density (HD) PE pipes. To locate underground magnetic PE pipes, it was experimentally determined that 4-inch diameter and larger pipes require an amount of about 17% by weight (w) of strontium ferrite powder and 2-inch diameter and smaller pipe sizes require an amount of about 24%w of strontium ferrite powder.

The specially compounded and extruded magnetic PE pipe materials were made by a major US pipe manufacturer. After the magnetic PE pipe was extruded and cooled during the manufacturing process, the pipe containing the magnetic filler passed through the cylindrical bore, an annular cavity, of a specially designed rotating “Permanent Magnet” (PM) magnetizer. The magnetizer consisted of several magnets, arranged in the form of a modified Halbach Dipole, mounted around the circumference of a chassis that rotated around the cylindrical bore through which the pipe passed. This magnet caused the pipe to be uniformly magnetized transversely across the diameter. Because of its rotational motion around the pipe, the magnetizer caused the magnetic particles in the pipe to be magnetized in a periodic spiral having an axis coincident with the pipe axis.

Figure 1 is a schematic illustration of the field of the specially designed “Permanent Magnet” used to magnetize a 2-inch pipe. The field of this “Permanent Magnetizer” is in the range of 6500G to 6000G- - 10^4 Gauss (G) =1 Tesla (T). In the POF, a specially designed and manufactured hand-held three-axis magnetic locator was used to locate the magnetic PE plastic pipe from above ground.

The cost of the POF magnetic PE pipe is about twice the cost of currently commercialized PE pipes. This high cost results primarily from the need to make the compounded PE resin and magnetic powder into pellets/beads prior to extrusion. The process involving making the compound into pellets is required because of the relatively high concentrations of 17%w and 24%w magnetic filler powder. By reducing the magnetic filler concentration to about 16%-14%, the cost of extruding the magnetic PE pipe could be reduced by about 50%.

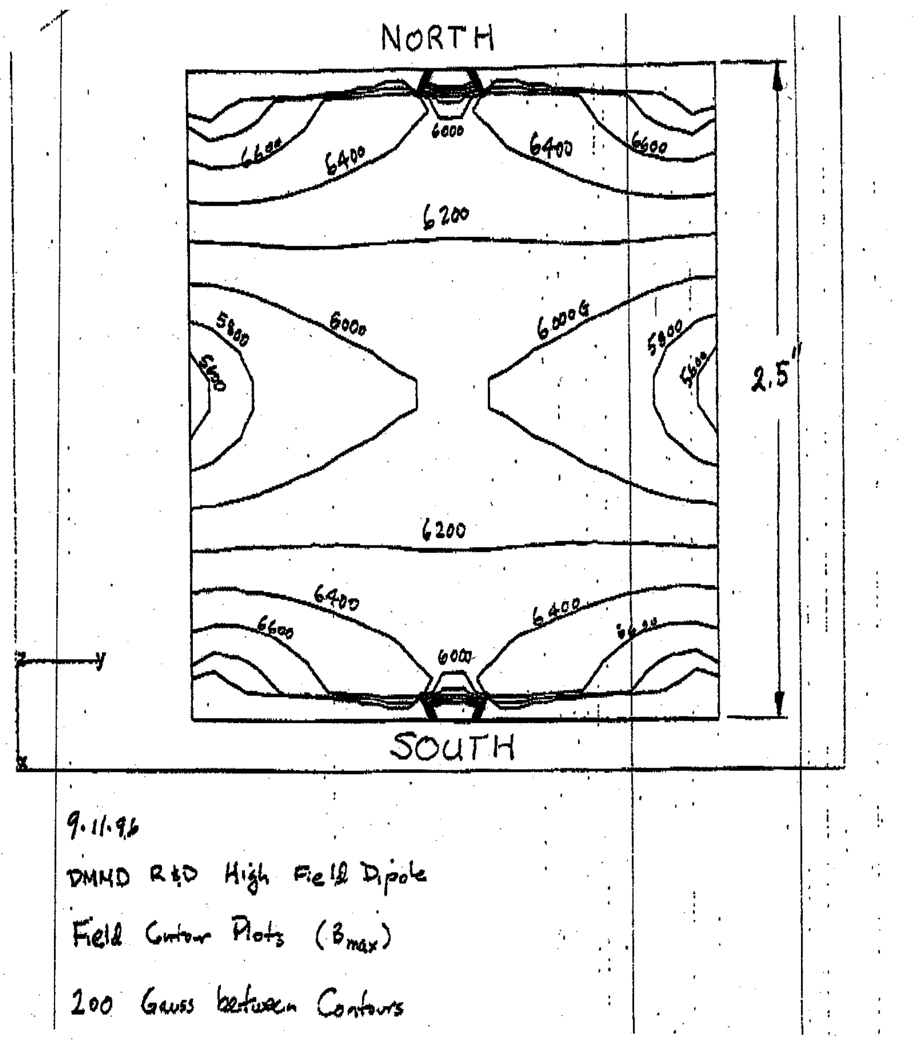

Figure 1. Schematic illustration of the 2-inch “Permanent Magnet” Magnetizer

With 16%-14%w magnetic particle concentration, the plastic PE resin containing the magnetic powder could be directly extruded into pipe form thus eliminating the additional cost incurred for producing pellets.

WORK COMPLETED DURING THE CURRENT REPORTING PERIOD: COMPLETION OF THE THIRD MILESTONE

In the current reporting period, several project activities making-up the Third Milestone were addressed and completed; these activities included the following tasks:

- Identify the technical feasibility of manufacturing, under laboratory conditions, magnetic compression molded (CM) plaques including 2-layer and 3-layer CM PE plaques to simulate a 2- and 3-layer co-extruded magnetic pipe,
- Manufacture under controlled laboratory conditions new CM PE plaques and 3-layered CM plaques,
- Experimentally determine and validate the magnetic field strength of new CM plaques magnetized using different techniques, and
- Conduct laboratory tests to generate data on the field strength of new magnetic CM PE plaques using various magnetization techniques.

Several laboratory experiments were conducted to determine whether or not the POF spirally magnetized PE pipes could be located from above ground. It was found that the magnetic field strength of these pipe materials was sufficiently high for the pipes to be located from above ground. The magnetic field strength of the POF PE pipes was then used as a benchmark reference/control in the testing and development work activities undertaken by GTI during the current reporting period.

To achieve expeditiously the research objective, it was determined that it would be least time consuming and least costly to manufacture in the laboratory, under controlled conditions, compression molded PE plaques containing various amounts, concentrations, and types of magnetic powder materials. These magnetic CM PE plaques would simulate extruded magnetic PE pipes.

Magnetic Multi-Layer Compression Molded PE Plaques

In the current reporting period, numerous laboratory experiments were undertaken and substantial work efforts were expended. These experiments involved making several one- layer, two-layer and three-layer magnetic CM PE plaques that simulated extruded magnetic PE pipes. Also, the laboratory experiments involved evaluating many different magnetization techniques to identify the one that would induce the most optimum magnetic field in the magnetic PE pipes and CM plaques simulating pipes. All of these laboratory experiments and trials were directed at both: reducing the amount of magnetic powder in the CM plaque simulating a PE pipe and maintaining the field strength at a magnitude equivalent to or greater than that of the POF magnetic PE pipe. Some of the laboratory work trials were successful and others were not; however, all of the laboratory work provided useful and significant information on how to achieve the objectives of this project.

Magnetic CM PE plaques simulating extruded PE pipes and multi-layered co-extruded pipes were manufactured in the laboratory. The width of each CM plaque test specimen is approximately 2-inch. These CM plaques were used to experimentally investigate the effects of various options including the use of reduced amounts and different types of magnetic powder and to identify the effects of implementing different magnetization techniques.

Because the POF magnetic HDPE pipe containing 24% w magnetic powder is used as a benchmark reference/control for pipes having an acceptable magnetic field strength that can be located from above ground, several CM plaques were made using this pipe material. These pipe materials were grounded-up and used to make several CM plaques in the laboratory. Figures 2 and 3 show photographs of a few of these reference plaques containing 24% magnetic filler powder used in the initial POF phase.

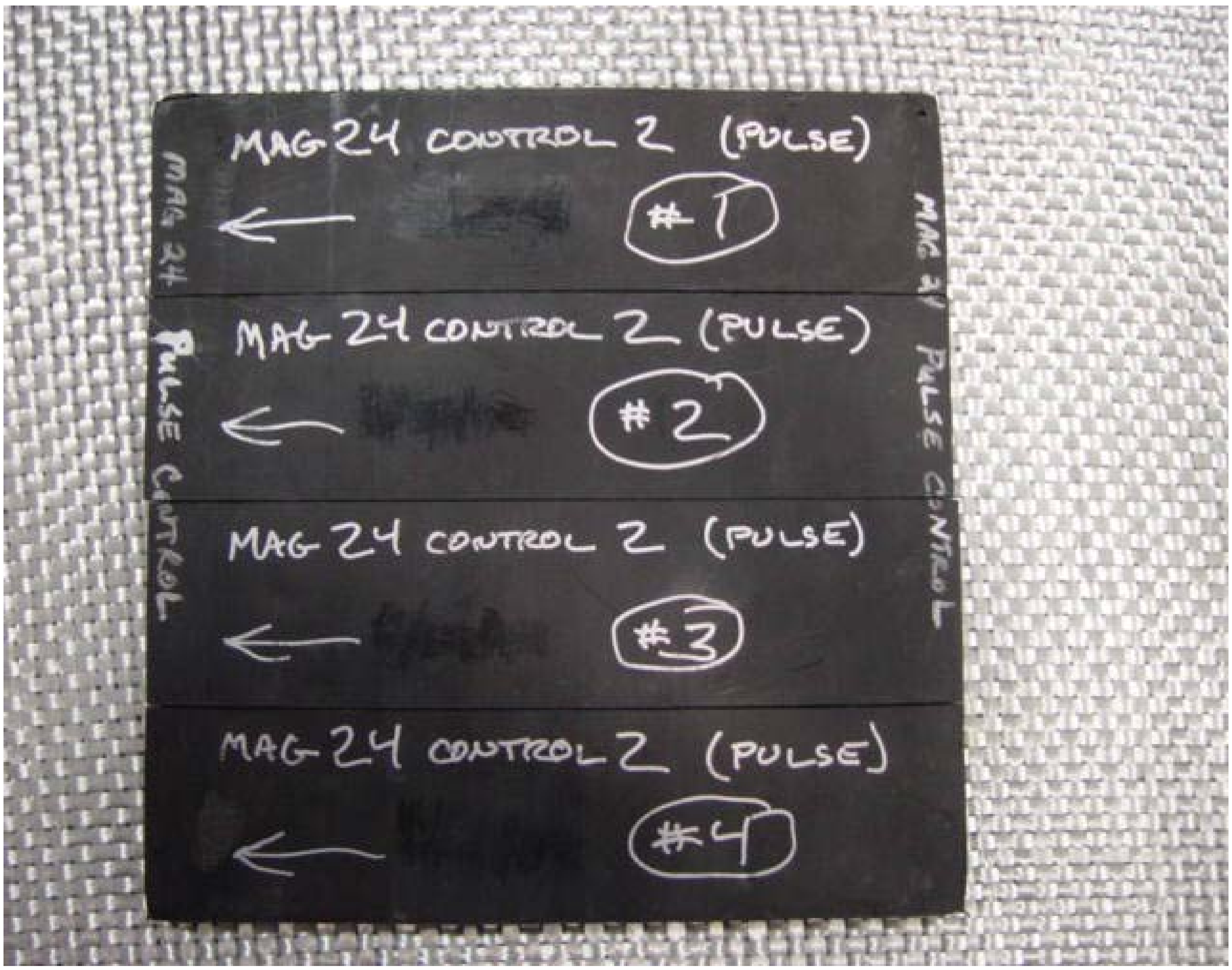

Figure 2. Photograph of a few CM HDPE Plaques, containing 24%w magnetic filler manufactured from the POF pipe, used for pulse axial magnetization

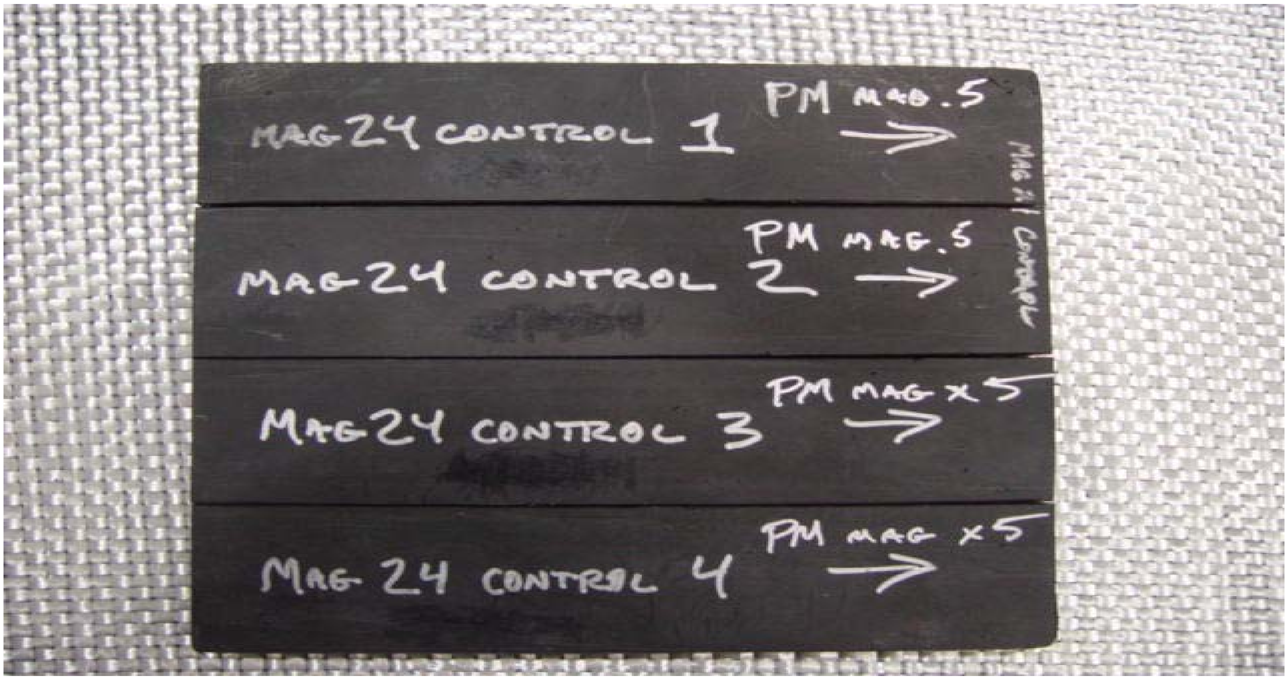

Figure 3. Photograph of a few CM HDPE plaques, containing 24%w magnetic filler manufactured from the POF pipe, used for transverse magnetization

Figure 4. Photograph of a few single layer homogenously mixed CM HDPE plaques containing 173 gm of a new magnetic powder designated as HM 185, and 547 gm of HDPE

During the current reporting period, it was discovered that a new magnetic strontium ferrite powder having a magnetic field strength substantially greater than that used in the POF phase was recently manufactured. This new powder, designated as HM 185, was purchased by GTI and was used for making new magnetic CM PE plaques. Figure 4 shows a photograph of a few CM plaques made with about 173 gm of HM 185 and about 547 gm of HDPE resin; this mixture represents about 24%w of magnetic powder. The CM plaques shown in Figure 4 were made by blending and homogeneously mixing the PE and the powder to make single layer plaques.

Magnetic CM PE plaques consisting of three layers were also manufactured under controlled laboratory conditions. Each of the two outer layers of the 3-layer CM plaques consisted of about 150 gm of only HDPE resin and the middle layer consisted of a homogeneous mixture made-up of 173 gm of HM 185 magnetic powder and 247 gm of HDPE. Again, these CM plaques represent about 24%w of the new magnetic powder. Figure 5 is a photograph of the 3-layer CM plaques containing 24%w of magnetic powder introduced into only the middle layer.

Several additional single-layer CM plaques were manufactured using different weight percentages of the new HM 185 magnetic powder. One-layer CM plaques consisting of homogeneous mixtures of 130 gm of HM 185 magnetic powder and 590 gm of HDPE resin were made; these plaques represent about 18%w of magnetic powder. Figure 6 depicts a photograph of these one-layer CM plaques.

Also, several one-layer CM plaques consisting of homogeneous mixtures of 87 gm of HM 185 magnetic powder and 633 gm of HDPE resin were made; these CM plaques represent materials containing about 12%w of magnetic filler. Figure 7 shows a few of the CM plaques with 12%w of HM 185 magnetic powder.

Many other types of CM plaques were manufactured including two-layer plaques. All of the manufactured plaques were made using the same processing conditions, molds, and equipment. All of the plaques were magnetized and their magnetic field measured in order to identify the optimum conditions.

Figure 5. Photograph of 3-layered CM plaques; each of the two outer layers consist of about 150 gm of HDPE and the middle layer consists of a homogeneous mixture made-up of 173 gm of HM 185 magnetic powder and 247 gm of HDPE

Figure 6. Photograph of a few single layer homogenously mixed CM HDPE plaques containing 130 gm of a new magnetic powder designated as HM 185 and 590 gm of HDPE

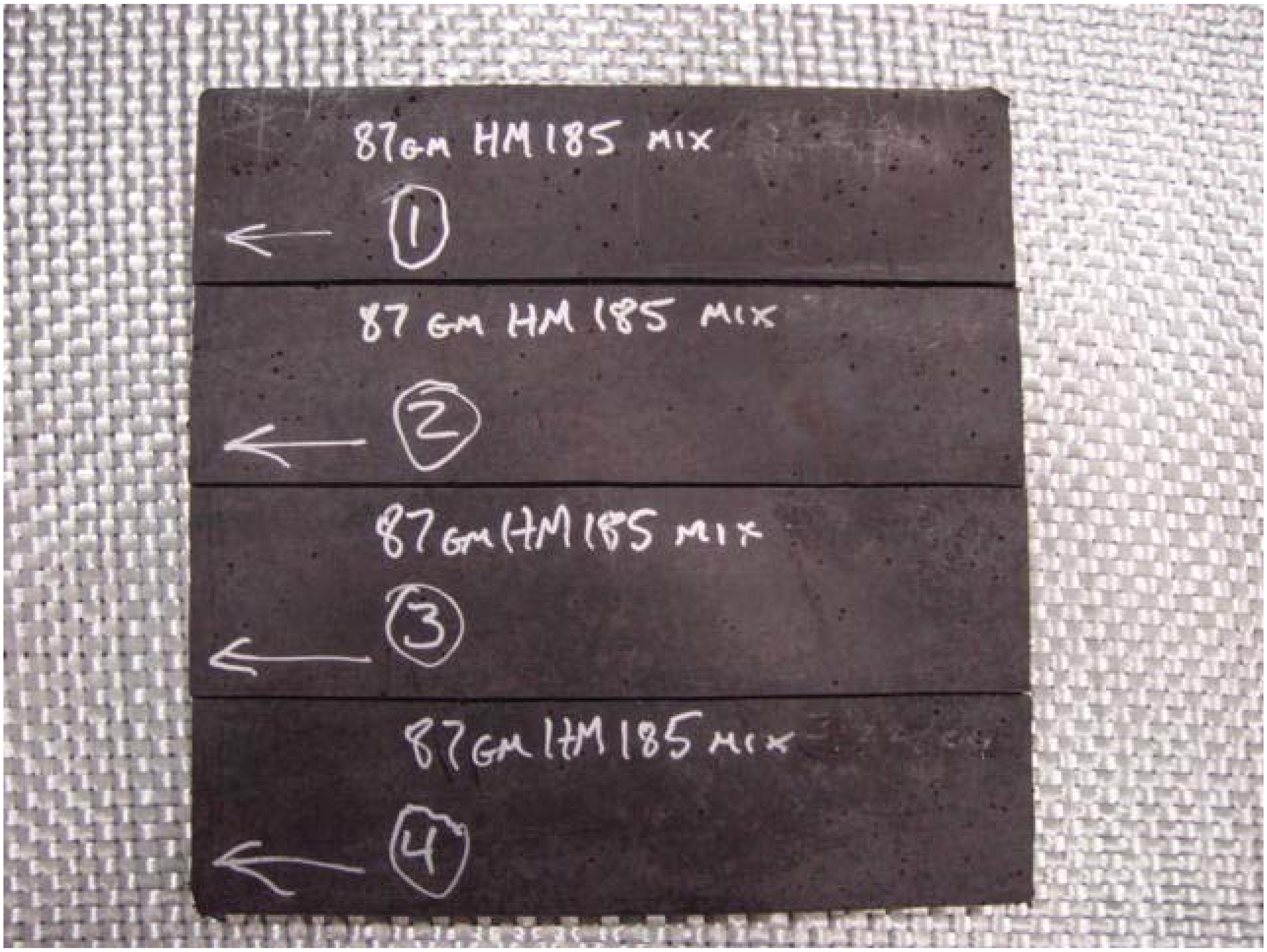

Figure 7. Photograph of a few single layer homogenously mixed CM HDPE plaques containing 87 gm of a new magnetic powder designated as HM 185 and 633 gm of HDPE

Magnetization Techniques

Numerous laboratory tests were undertaken to identify the magnetization technique(s) that would induce the greatest magnetic fields in the magnetic test plaques/pipes. Many laboratory experiments were performed to determine the effect, on the transverse magnetic field induced in the pipe specimens and CM test plaques, of the number of passes through the PM magnetizer. Similarly, experiments were conducted to determine the effect, on the axial magnetization induced in the pipe samples and the CM test plaques, of the number of pulses, number of dipoles, overlapping dipoles, and dipole alignment.

Three magnetization techniques were implemented and examined; these included:

- The initial POF transverse spiral magnetization (SM) using the rotating Permanent Magnet depicted schematically in Figure 1;
- Transverse magnetization (TM) using the PM depicted in Figure 1 but with a non-rotating stationary chassis; and
- Pulse Axial Magnetization (AM) using the Pulse Magnetizer shown in Figure 8.

Figure 9 shows both the Pulse Magnetizer and the 2-inch Rotating Permanent Magnet Magnetizer. For pulse axial magnetization, several magnetic/induction coils were designed, fabricated and used. The two coils that were most frequently used are shown in Figure 10.

Figure 8. Photographic view of the Pulse magnetizer

Figure 9. Photographic view of the Pulse Magnetizer (front white) and the Rotating Permanent Magnet magnetizer (rear tan)

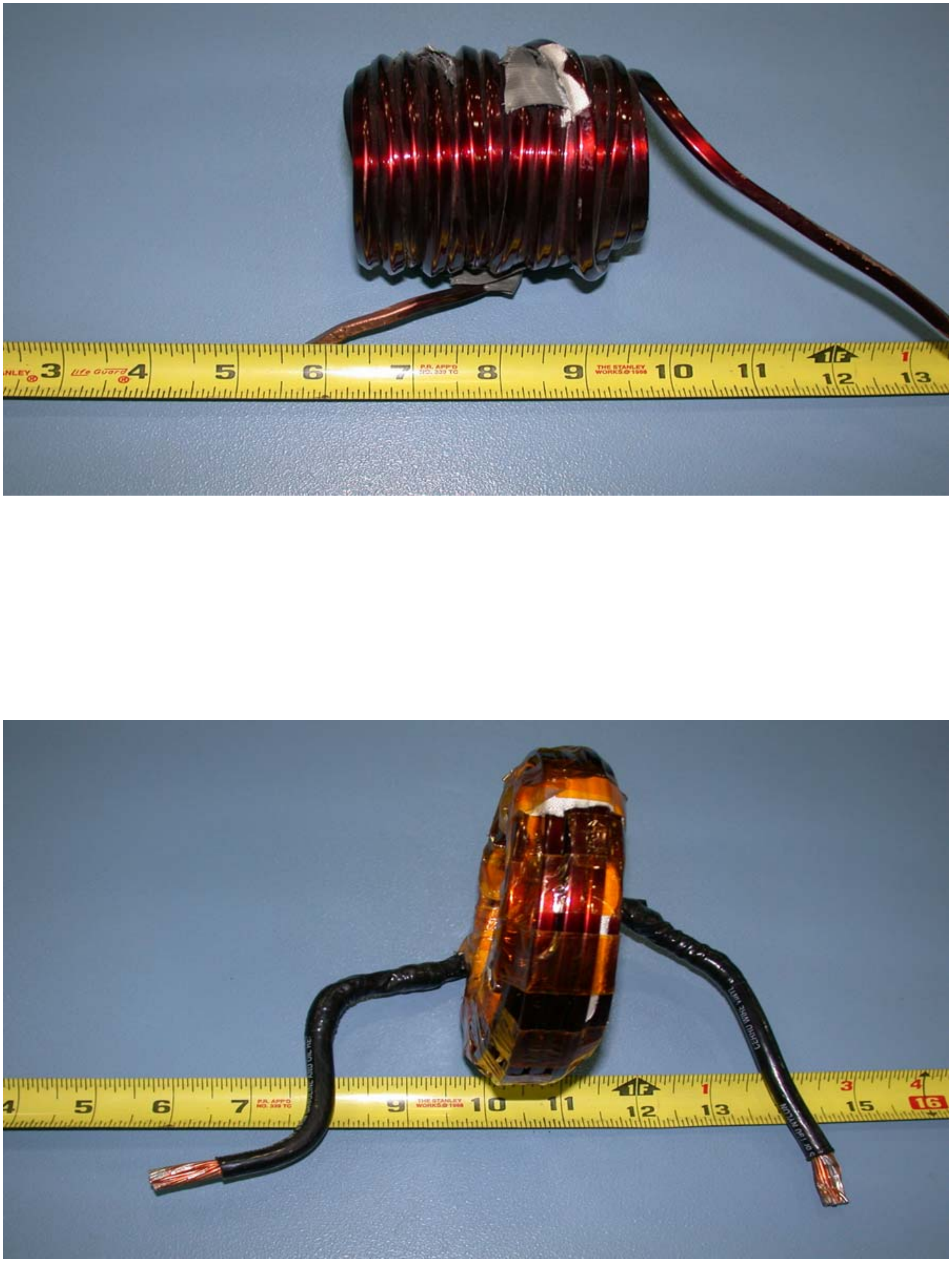

Figure 10. Magnetic Coils: top coil 3.25-inch wide and bottom coil 1.25-inch wide

Experimental Measurement of the Induced Magnetic Field in the Pipe Specimens and the CM Plaque Test Specimens

Measurements of the resultant magnetic field of the pipe specimens and the rectangular CM test specimens were undertaken using a Fluxgate magnetometer probe placed on a flat non-magnetic rectangular surface. A photographic view of the Fluxgate probe and the laboratory measurement set-up to determine the field strength of the pipe samples and the rectangular CM plaque test specimens is shown in Figure 11. All the test samples were placed at a distance of 30 inches from the probe, as shown schematically in Figure 12, and the magnetic field components were measured. Using the Fluxgate magnetometer, the x-, y-, and z-components of the pipe samples and CM test specimens were measured and the resultant magnitude of the magnetic field was computed.

In all the laboratory magnetic field measurements, the pipe and the CM rectangular test specimen were placed so that the specimen's longitudinal (y-) axis was perpendicular to the longitudinal (x-) axis of the Fluxgate probe as shown in Figure 12; this orientation is designated as the 90 degrees orientation.

Figure 11. Photographic view showing the Fluxgate magnetometer placed on a non-magnetic table

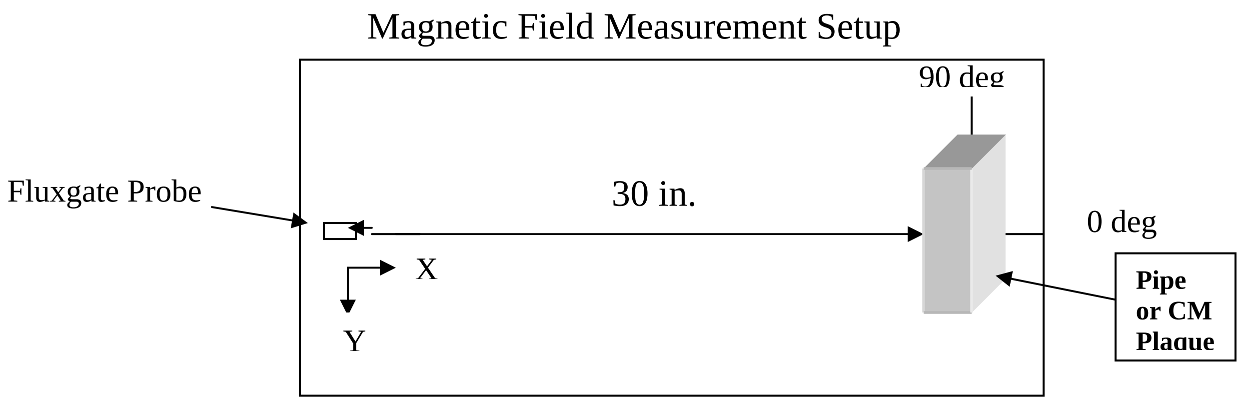

Figure 12. A schematic showing the laboratory Fluxgate magnetometer probe set-up for the measurement of the magnetic field strength

<u>Magnetic Field Strength of the Spirally Magnetized POF PE Pipe Containing 24%w Magnetic Powder</u>

Because the POF PE pipe containing 24%w of magnetic powder was locatable from above ground to a depth of about 5 feet, the magnetic field strength of this pipe was used as a benchmark reference. In all of the laboratory measurements, the test specimen was placed so that its longitudinal axis was perpendicular to the axis of the magnetometer probe. In all the experiments on pipe specimens and CM specimens, it was found that the magnetic field strength increased with increasing sample length. With pipe specimens, the magnetic field strength increased until the test specimen length was about 48-60 inch. For greater pipe specimen lengths, the magnetic field strength retained a constant value. Hence, magnetic field strengths should be compared for test samples of the same length.

For the spirally magnetized benchmark reference 24%w magnetic pipe, the magnetic field strength was measured for different pipe specimen lengths including 8.75-inch, 18-inch, 24-inch, and 36-inch. Several test specimens having the same length were prepared, magnetized and measured. For each test sample in a set of specimens with the same length, the X-, Y-, and Z-components of the magnetic field were measured and the field resultant was computed. Then, the average resultant of the set of test samples was calculated. Depending on the availability and amount of manufactured test pipe and CM test plaques the number of specimens in a test set varied between two and 5 specimens.

The spiral magnetization was produced as the PE pipe was passed through the annular gap of the rotating PM magnetizer. This magnetization technique induced magnetic dipoles across the pipe diameter aligned along a spiral running down the pipe axis. Foe each set of test specimens. Table 1 gives the measured X-, Y-, and Z- components and the resultant of the magnetic field of each pipe specimen. Also, Table 1 gives the average of the resultant for each set of specimens having the same length. All of the reported magnetic field measurements are presented in units of Nano-Tesla (nT); 1 Tesla (T) $=10^4$ Gauss (G). The laboratory test data presented in Table 1 show that for an 8.75-, 18-, 24-, and 36-inch long pipe specimens the average resultant of the magnetic field is 641 nT, 1203 nT, 1578 nT, and 1881 nT, respectively.

Magnetic Field Strength of the Transversely Magnetized POF PE Pipe Containing 24%w Magnetic Powder

The POF PE pipe containing 24%w magnetic powder was re-magnetized by passing it through the bore of the PM magnetizer with the chassis stationary, i.e., non-rotating. This induced magnetic dipoles transversely through the pipe diameter. To determine the effects of passing the magnetic pipe through the PM bore repeatedly, several experiments were conducted by repeatedly passing the test pipe specimens 1, 5, 10, 20 and 50 passes. The magnetic field was measured after 1, 5, 10, 20, and 50 passes. The results showed that the magnetic field is fully induced after about 5 passes.

Four sets of experiments were performed involving the transverse re-magnetization of the 24%w POF PE pipe. Each set consisted of several test replicates of the same length. The sets included pipe lengths of 8.75-, 17.5-, 26.25, and 35-inch. Each pipe specimen in each set was re-magnetized by passing it through the stationary PM magnetizer 5 times. The magnetic field strength of each test specimen was measured and the resultant of the field was computed. Also, the average resultant of the vectorial magnetic field of each set was determined. Table 2 presents the laboratory test data of the magnetic field measurements for these sets of transversely re-magnetized pipes. Table 2 shows that for the transversely re-magnetized pipe specimens having a length of 8.75-, 17.5-, 26.25-, and 35-inch, the resultant of the magnetic field is 628 nT, 1117 nT, 1401 nT, and 1820 nT, respectively.

The data presented in Tables 1 and 2 show that the magnetic field strength of a 24% w POF PE pipe specimen with a length of about 35-inch is about 1820-1850 nT for both spiral magnetization and transverse magnetization. That is, spiral magnetization (SM) and transverse magnetization (TM) induce equivalent magnetic fields.

Magnetic Field Strength of the Axially Magnetized POF PE Pipe Containing 24%w Magnetic Powder

Numerous experiments were performed to determine the advantages and limitations of axial magnetization using the Pulse Magnetizer and the induction coils shown in Figures 8 and 10. Axial magnetization laboratory tests were performed on pipe specimens and CM plaques to determine the effects on the magnetic field of the number and spacing of the induced dipoles, number of pulses conducted to create a dipole, and alignment of dipoles.

The POF PE pipe containing 24%w magnetic powder was axially re-magnetized. Several parameters were evaluated including the use of different induction coils. Specimens of this pipe with different lengths including 18-, 36-, 54-, and 72-inch were axially magnetized using a 3.25-inch wide coil. Aligned magnetic dipoles (N-S-N-S-N..) were induced in the pipe specimens; five pulses were performed at each dipole. Each pair of dipoles was separated by a distance of about 1/8-inch. The components of the magnetic field of the axially magnetized pipe were measured and the resultant was calculated.

Table 3 lists the laboratory test data for each axially magnetized pipe specimen. The data show that for the 18-, 36-, 54-, and 72-inch long specimens, the resultant field is 521 nT, 721 nT, 597 nT, and 570 nT, respectively. With axial magnetization the magnetic field strength attains a maximum value for a specimen length of about 36-inch.

The laboratory test data presented in Tables 1, 2, and 3 show that spiral or transverse magnetization induce a magnetic field that is more than twice the magnetic field induced using axial magnetization.

Magnetic Field Strength of CM Plaques Made from the POF PE Pipe Containing 24%w Magnetic Powder

For comparative laboratory evaluations, the POF PE pipe containing 24%w of magnetic powder is used as a benchmark reference since it was locatable from above ground to a depth of about 5 feet. To compare the performance of the newly made CM plaques using the recently acquired magnetic powder HM185, the 24%w POF pipe was grounded-up to make CM plaques under laboratory conditions. The magnetic field strength of these CM plaques, designated as 24%w POF CM Plaques, is used as a benchmark reference.

Transverse Magnetization of 24%w POF CM Plaques

Several laboratory experiments were performed on these CM plaques to determine the effects of different magnetization techniques on the field strength. The 24%w POF CM plaque specimens were magnetized transversely by passing them through the bore of the stationary PM magnetizer. Each CM plaque test specimen was passed five times through the PM magnetizer to induce a TM field. Plaques with different lengths were evaluated to determine their magnetic field strength. The X-, Y-, and Z-components of the field were measured using the magnetometer probe and the resultant field strength was computed.. For each specimen length, several test replicates were made and tested. Laboratory magnetization experiments and field measurements were performed for several test replicates and sets of specimens with different lengths.

Table 4 lists the magnetic field strength data for the transversely magnetized 24% w POF CM plaque specimens with a length of 8.75-, 17,5-, 26.25-, and 35-inch. The test data show that for the 8.75-, 17,5-, 26.25-, and 35-inch sets, the average resultant of the magnetic field is 380 nT, 705 nT, 776 nT, and 1176 nT, respectively. The field strength increases with increasing specimen length. The data show that the field strength for the 24%w POF CM plaque specimens is less than that of the corresponding pipe specimens. It is believed that this is due to the fact that the field of a pipe specimen would be equivalent to the field of two plaques stacked back-to-back.

Axial Magnetization of 24%w POF CM Plaques

Axial magnetization laboratory experiments were performed on the 24%w POF CM plaque specimens to determine the effects of AM techniques on the field strength. Magnetic dipoles were induced axially by placing the specimen within the 3.25-inch wide coil and pulsing five times. Several aligned dipoles were induced in each CM plaque specimen. The magnetic field components were measured for each specimen length. Table 5 gives the laboratory test data for the axially magnetized 24%w POF CM plaque specimens. Table 5 shows that for CM plaque lengths of 8.75-, 17.5-, and 26.25-inch the average field resultant is 244 nT, 422 nT, and 542 nT, respectively. Comparitive evaluations of the data in Tables 4 and 5 show that transverse magnetization induces a greater magnetic field in the 24%w POF CM plaque specimens than axial magnetization.

Magnetic Field Strength of Single Layer Homogenously Mixed CM Plaques Containing 173 gm of HM 185 Magnetic Powder: 24%w HM 185

A few single layer CM plaques containing about 173 gm of HM 185 and about 547 gm of HDPE resin were manufactured under laboratory conditions; this mixture represents materials consisting of about 24%w of magnetic powder. These CM Plaques, designated as 24%w HM 185, were made by homogenously mixing the magnetic powder and the PE resin. Replicates of different lengths of these CM test specimens were magnetized both transversely and axially. Again, it was found that transverse magnetization induces a magnetic field greater than axial magnetization.

Table 6 lists the measured components of the magnetic field for several specimens of with a length of 8.75-, 17.5-, 26.25-, and 35- inch. For these TM specimen lengths, the magnitude of the average magnetic resultant is 540 nT, 1034 nT, 1344 nT, and 1635 nT, respectively.

Tables 4 and 6 may be used to perform a comparative evaluations of the magnetic field for the 24%w POF CM specimens using the previous magnetic powder and the 24%w HM 185 CM specimens using the new magnetic powder. This comparison is presented below:

Specimen Length	8.75-inch	17.5-inch	26.25-inch	35- inch
24%w POF, nT	380	705	976	1176
24%w HM 185, nT	540	1034	1344	1635

The results of the comparative evaluations show that the new HM 185 magnetic powder results in a magnetic field strength that is about 40% greater than the field strength induced using the previous POF magnetic powder.

In view of these encouraging results, additional CM plaques containing 130 gm and 87 gm of HM 185 were manufactured and evaluated. The mixture containing 130gm and 87 gm represent materials consisting of about 18%w and 12%w of magnetic powder.

<u>Magnetic Field Strength of 3-Layer CM Plaques Containing 173 gm of HM 185 Magnetic Powder</u>

To determine the effects of concentrating the amount of magnetic powder in a smaller volume than that with a single layer, as described above, CM PE plaques consisting of three layers were also manufactured under controlled laboratory conditions. Each of the two outer layers of the 3-layer CM plaques consisted of about 150 gm of only HDPE resin and the middle layer consisted of a homogeneous mixture made-up of 173 gm of HM 185 magnetic powder and 247 gm of HDPE resin.

These 3-layer CM plaques were magnetized transversely and axially. Table 7 gives the measured components of the magnetic field and the computed resultant for different specimen lengths.

Comparative evaluations of the laboratory test data presented in Tables 6 and 7 show that the magnetic field strength for the one-layer homogenous CM plaques is about the same as that of the 3-layer CM plaques. This result indicates that the field strength is the same for similar amounts by weight of magnetic powder. Also, the results show that a 3-layer co-extruded pipe can be made in which the outer and inner layers are PE resins and the middle unexposed layer contains the magnetic powder. This is important for several applications including water pipes.

<u>Magnetic Field Strength of One-Layer CM Plaques Containing 130 gm of HM 185 Magnetic Powder</u>

A few single layer CM plaques containing about 130 gm of HM 185 and about 590 gm of HDPE resin were manufactured under laboratory conditions; this mixture represents materials consisting of about 18%w of magnetic powder. These CM Plaques, designated as 18%w HM 185, were made by homogenously mixing the magnetic powder and the PE resin. Replicates of different lengths of these CM test specimens were magnetized both transversely and axially. It was found that transverse magnetization induces a magnetic field greater than axial magnetization.

Table 8 lists the measured X-, Y-, and Z-components of the magnetic field for several specimens with a length of 8.75-, 17.5-, 26.25-, and 35- inch. For these TM specimen lengths, the magnitude of the average magnetic resultant is 394 nT, 747 nT, 1027 nT, and 1280 nT, respectively.

Tables 4, 6 and 8 may be used to perform a comparative evaluation to determine the effects, of using the POF magnetic powder and the effects of using the new HM 185 magnetic powder in amount of 24%w and 18%w, on the magnetic field of One-Layer CM plaque specimens. This comparison is presented below:

Specimen Length	8.75-inch	17.5-inch	26.25-inch	35- inch
24%w POF, nT	380	705	976	1176
24%w HM 185, nT	540	1034	1344	1635
18%w HM 185, nt	394	747	1027	1280

This comparative evaluation shows that the magnetic field strength of CM plaques with 18% (130gm) HM185 is approximately 10% greater than that of the POF CM plaques containing 24%w of the previous magnetic powder. The field strength of 18%w HM 185 CM plaques is about 30% less than that corresponding to 24%w HM 185 CM plaques.

Laboratory tests were also performed on CM plaques containing 87gm HM 185 powder. However, the test data are not conclusive; additional plaques will be manufactured and re-evaluated.

RESULTS AND CONCLUSIONS

The work accomplishments during the current reporting period, led to several important results and conclusions including the following:

- A newly marketed magnetic powder, designated as HM 185, has been used in making CM plaques simulating one-, two-, and three-layer co-extruded PE pipes.
- CM plaques containing about 130 gm of HM 185 represent pipe materials containing 18% w of magnetic powder; these CM plaques have a magnetic field strength that is about 10% greater than the original POF pipes which contained about 24% w of magnetic powder.
- The results show that if HM 185 is used then the amount of magnetic powder may be reduced by at least 16% compared to the POF pipe and still induce a magnetic field equivalent to the POF pipe.
- The results indicate that spiral magnetization using a rotating PM induces a magnetic field equivalent to transverse magnetization using a non-rotating PM.
- The laboratory test data show that spiral magnetization or transverse magnetization induces an optimum magnetic field having a strength significantly greater than that obtained with axial magnetization.

Table 1. Field Strength of 24%w Pipe with Spiral Transverse Magnetization, nT

Pipe Lengths: 8.75, 18.00, 24, and 36 inches

SPECIMEN		COMPONENT				AVERAGE
LENGTH [inches]	NUMBER	X	Y	Z	RESULTANT	RESULTANT
8.75	1	-642	42	15	643	
	2	-646	74	29	651	
	3	-631	67	-11	635	
	4	633	12	-16	633	641
18	1	1296	203	64	1313	
	2	1121	42	61	1123	
	3	1139	45	83	1143	
	4	1205	74	13	1207	
	5	1224	84	50	1228	1203
24	1	1561	144	3	1568	
	2	1577	163	58	1586	
	3	1567	190	86	1581	1578
36	1	1827	97	60	1831	
	2	1899	46	23	1900	
	3	1907	55	130	1912	1881

Table 2. Field Strength of 24% w pipe Transversely Re-Magnetized, nT

Pipe Lengths: 8.75, 17.5, 26.25, and 35 inches

SPECIMEN		COMPONENT				AVERAGE
LENGTH [inches]	NUMBER	X	Y	Z	RESULTANT	RESULTANT
8.75	1	-621	10	10	621	
	2	-628	-25	-30	629	
	3	-655	4	-40	656	
	4	-607	3	-14	607	628
17.5	1	1061	-169	12	1074	
	2	-1102	-118	-51	1109	
	3	-1127	196	37	1145	
	4	1110	-156	67	1123	
	5	-1067	-55	-92	1072	
	6	1165	-153	81	1178	1117
26.25	1	1355	-115	406	1419	
	2	1354	-57	361	1402	
	3	1339	-56	343	1383	1401
35	1	1828	-63	-22	1829	
	2	1809	-79	-31	1811	1820

Table 3. Field Strength of 24%w Pipe with Axial Magnetization, nT

Pipe Lengths: 8.75, 18.00, 24, and 36 inches

SPECIMEN		COMPONENT				AVERAGE RESULTANT
LENGTH [inches]	NUMBER	X	Y	Z	RESULTANT	
18.00	1	29	525	-17	526	
	2	17	516	-3	516	
	3	-17	522	8	523	
	4	41	519	-6	520	521
36	1	65	720	-15	723	
	2	43	716	-20	718	
	3	52	721	-23	723	
	4					
	5					721
54	1	122	655	7	666	
	2	27	570	60	574	
	3	39	549	44	551	597
72	1	77	565	2	570	570
	2					
	3					

Table 4. Magnetic Field Strength of Transversely Magnetized 24%w POF CM Plaques, nT

Coupon Lengths: 8.75, 17.5, 26.25, and 35 inches

SPECIMEN		COMPONENT				AVERAGE
LENGTH [inches]	NUMBER	X	Y	Z	RESULTANT	RESULTANT
8.75	1	358	-31	85	369	
	2	392	34	70	394	
	3	382	10	60	387	
	4	361	29	86	372	380
17.5	1	689	62	141	706	
	2	666	60	131	681	
	3	648	57	151	668	
	4	732	25	107	740	
	5	703	27	133	133	
	6	710	38	126	722	705
26.25	1	960	34	175	976	
	2	925	17	192	945	
	3	979	25	193	998	
	4	960	50	212	984	976
35	1	1144	26	221	1165	
	2	1161	60	236	1186	1176

Table 5. Magnetic Field Strength of Axially Magnetized CM Plaques Made from 24%w POF Pipe , nT

USING PULSE MAGNETIZER: 5 Pulses at Each End
Coupon Lengths: 8.75, 17.5, and 26.25 inches

SPECIMEN		COMPONENT				AVERAGE
LENGTH [inches]	NUMBER	X	Y	Z	RESULTANT	RESULTANT
8.75	1	-9	246	-15	247	
	2	-14	227	-8	228	
	3	-19	244	-6	245	
	4	-15	256	-9	257	244
17.5	1	-41	415	-4	417	
	2	-28	405	-6	406	
	3	-14	426	4	426	
	4	-12	440	2	440	422
26.25	1	-16	542	-3	542	542

Table 6. Magnetic Field Strength of Transversely Magnetized Single Layer Homogenous 24%w HM 185 CM Plaques

Coupon Lengths: 8.75, 17.5, 26.25, and 35 inches

SPECIMEN		COMPONENT				AVERAGE
LENGTH [inches]	NUMBER	X	Y	Z	RESULTANT	RESULTANT
8.75	1	-529	-50	161	555	
	2	-505	-29	171	534	
	3	-531	-43	179	562	
	4	-485	-58	148	510	540
17.5	1	-1024	-37	330	1076	
	2	-1037	-44	334	1090	
	3	-996	-55	297	1041	
	4	-1062	-61	349	1195	
	5	-1014	-70	327	1068	1094
26.25	1	-1306	-99	422	1376	
	2	-1248	-82	400	1313	1344
35	1	-1530	-137	561	1635	1635

Table 7. Magnetic Field Strength of Transversely Magnetized 3-Layer 173 gm (24%w) HM 185 CM Plaques

SPECIMEN		COMPONENT				AVERAGE
LENGTH [inches]	NUMBER	X	Y	Z	RESULTANT	RESULTANT
8.75	1	-503	10	49	505	
	2	-579	7	132	594	
	3	-539	13	69	544	
	4	-526	29	84	533	544
17.5	1	992	28	144	1003	
	2	1032	82	56	1037	
	3	980	29	84	984	
	4	960	20	89	964	
	5	1030	55	141	1041	
	6	-1006	28	143	1016	1007
26.25	1	-1372	-9	206	1387	
	2	1297	-30	150	1306	
	3	1361	-23	249	1384	
	4	1354	-24	220	1372	1362
35	1	-1552	40	262	1574	
	2	-1550	37	268	1573	
	3	1522	28	262	1545	1564

Table 8. Magnetic Field Strength of Transversely Magnetized 1-Layer 130 gm (18%w) HM 185 CM Plaques

Specimen Lengths: 8.75, 17.5, 26.25, and 35 inches

SPECIMEN		COMPONENT				AVERAGE
LENGTH [inches]	NUMBER	X	Y	Z	RESULTANT	RESULTANT
8.75	1	-349	-30	101	364	
	2	-407	-23	100	420	
	3	-399	-24	124	419	
	4	-358	-19	108	374	394
17.5	1	-715	-50	188	740	
	2	-708	-56	215	742	
	3	-676	-45	195	705	
	4	-757	-62	213	788	
	5	-725	-62	196	753	
	6	-720	-70	228	752	747
26.25	1	-998	-85	282	1040	
	2	-977	-110	264	1018	
		-1020	-104	299	1068	
	3	-944	-79	296	984	1027
35	1	1239	-48	319	1280	
		1256	-44	331	1300	
	2	1219	-41	316	1260	1280